

LA-UR-19-32748

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Title: Protocol for Determining Actual Flow Rate in FTWC Duct Systems

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Intended for: FTWC Area G Project Files

Issued: 2020-01-31 (rev.1)

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Protocol for Determining Actual Flow Rate in FTWC Duct Systems

Abstract

This paper is intended to document the theory and methods to determine the actual flow rate in the exhaust system used to ventilate the Flanged Tritium Waste Containers based on real-time instrument readings. Section 1 provides introductory and background material; Section 2 details the various correction factors used to adjust flow readings for ambient air pressure and temperature and other operational parameters. Section 3 provides guidance on implementing this process during venting operations, and Section 4 provides supporting documentation and also a field checklist that can be used by personnel during venting. **For Revision 1, a summary of editorial changes made to the paper was added as Section 4.4, as well as a section documenting peer review (Section 4.5).**

1.0 Introduction

It is necessary to vent a series of Flanged Tritium Waste Containers (FTWCs) which are currently in storage at Technical Area (TA) 54, Materials Disposal Area G at Los Alamos National Laboratory (LANL). A controlled vent system is needed to **safely** vent these containers and measure any emissions that may be released to the environment. A complete description of the FTWCs and associated issues is contained **in** the Radionuclide NESHAP¹ Application for Pre-Construction Approval for the project.² The Radioactive Air Emissions Management (RAEM) team in LANL's Environmental Compliance Programs Group (EPC-CP) is responsible for measuring emissions and calculating subsequent off-site dose consequences from these FTWC venting operations. This document describes theory and methods to ensure adequate flow is maintained in the FTWC exhaust duct.

1.1 Safety Concerns

The headspace gas within the FTWCs may contain hydrogen gas, in unknown ratios with air or other gases. Due to the explosive nature of hydrogen gas, the FTWC headspace gas must be vented in a manner that will ensure the hydrogen concentration in the ventilation system will not reach a flammable or explosive concentration. The Lower Explosive Limit (LEL) for hydrogen is 4% by volume.^{3,4} Common safe practice under OSHA is to have sufficient ventilation to keep the

¹ Title 40, Code of Federal Regulations, Part 61, Subpart H. National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities. Referred to as the Rad-NESHAP or Radionuclide NESHAP.

² LA-UR-18-26283r2, Application for Pre-Construction Approval under 40 CFR 61 Subparts A and H for Venting of Flanged Tritium Waste Containers (FTWCs) at TA-54. May 16, 2019. Submitted to EPA Region 6 as part of letter EPC-DO-19-137, May 17, 2019.

³ Safety Data Sheet for Hydrogen, Airgas. Issued February 2, 2018.

⁴ The Engineering Toolbox. Gases – Explosion and Flammability Concentration Limits. Retrieved 12/20/2019. https://www.engineeringtoolbox.com/explosive-concentration-limits-d_423.html

concentration of hydrogen to one-fourth of the LEL, or less than 1% hydrogen concentration by volume.^{4,5} This document describes methods for verifying the duct flow rate is above the level needed to meet this 1% requirement.

1.2 Flow rate from FTWC

The total pressure of the headspace gas is unknown, as is the composition of the headspace gas. Several assumptions have been made regarding worst-case bounding scenarios. Venting equipment will be equipped with a Reduced Flow Orifice (RFO) to control the maximum flow rate out of the FTWC and discharging into the ventilation ductwork. A complete description of the FTWC ventilation equipment and RFO calculations are described in a LANL engineering calculation.⁶ The calculation looks at two venting scenarios: the first using a larger 2 horsepower (HP) blower in the duct system and the second using a smaller ¾ HP blower in the system. The larger system is used for initial venting operations at TA-54, while the smaller blower system will be used if secondary venting operations must be conducted at other sites (e.g., outside the Weapons Engineering Tritium Facility (WETF) at TA-16).

This calculation assumes the headspace of the FTWC is pure hydrogen and determines the maximum flow rate of FTWC headspace gas that can be safely discharged into the duct system. To keep this FTWC headspace gas under the safe threshold of 1% concentration by volume, the total flow rate through the duct must be 100 times this FTWC ventilation rate. The end results of the calculation is that the duct flow rate must be 1,476 actual cubic feet per minute (acfm) in the large-blower system and 753 acfm in the small-blower vent system.

1.3 Ideal Gas Law relationships

The behavior of gases at different temperature and pressures is given by the ideal gas law.

$$P * V = n * R * T$$

(Equation 1)

Where:

P = Pressure of a gas; typically in units of atmospheres

V = Volume of a gas; typically in cubic feet

n = Number of moles of a gas (quantity)

⁵ Title 29, Code of Federal Regulations, Part 1910.106(a)(31). United States Department of Labor, Occupational Safety & Health Administration. Definition of ventilation.

⁶ Calculation WETF-CALC-TCV-19-006. FTWC Area G – Reduce Flow Orifice Diameter Sizing to Provide Less Than or Equal to 1% of Flow Through the Orifice Compared to Flow Through a Blower Manifold. Mark Bibeault, 10/8/2019.

R = Ideal Gas Constant

T = **Temperature** of the gas

For a given quantity of gas (constant “n”) and removing the Ideal Gas Constant, the relationship between volume, pressure and temperature of this quantity of gas at different conditions can be given by the combined gas law.

$$\frac{P_1 * V_1}{T_1} = \frac{P_2 * V_2}{T_2}$$

(Equation 2)

Where:

P₁, V₁, and T₁ = Pressure, temperature, and volume of a given quantity of gas at condition 1

P₂, V₂, and T₂ = Pressure, temperature, and volume of a given quantity of gas at condition 2

To determine the volume at one condition relative to the volume at another condition, the above equation can be rearranged as shown below.

$$V_2 = V_1 * \left(\frac{T_2}{T_1}\right) * \left(\frac{P_1}{P_2}\right)$$

(Equation 3)

The parameter of concern for this operation is volumetric flow. This is defined as the change in volume over the change in time.

$$\dot{V} = \frac{\Delta Volume}{\Delta time}$$

(Equation 4)

In all of the equations here, one can simply replace the fixed volume V with **volumetric** flow rate \dot{V} .

$$\dot{V}_2 = \dot{V}_1 * \left(\frac{T_2}{T_1}\right) * \left(\frac{P_1}{P_2}\right)$$

(Equation 5)

For this document, the primary concern is converting a flow rate from “standard conditions” to determine the actual flow rate through the exhaust duct.

$$\dot{V}_{act} = \dot{V}_{std} * \left(\frac{T_{act}}{T_{std}}\right) * \left(\frac{P_{std}}{P_{act}}\right)$$

(Equation 6)

Where:

P_{std} , T_{std} , and \dot{V}_{std} = Pressure, temperature, and volumetric flow of a given quantity of gas at standard conditions; $T_{std} = 70^\circ \text{ F}$; $P_{std} = 1 \text{ atmosphere}$

P_{act} , T_{act} , and \dot{V}_{act} = Pressure, temperature, and volumetric flow of a given quantity of gas at actual conditions at the time of measurement

The gas in the duct is at least 99% air (by volume) according to the requirements of Section 1.1. Therefore, all calculations in this document will be performed assuming the gas in the duct has the properties of ambient air.

2.0 Exhaust system flow determinations

At LANL, flow measurements for radionuclide air emissions compliance calculations are done per EPA methods.⁷ These EPA methods involve measuring air velocity at multiple points across the cross-sectional area of the duct, and then these readings are combined to determine the average air velocity through the system. These measurements take around 30 minutes to measure air velocity at all points across a duct, and therefore do not lend themselves to real-time flow determinations.

To determine flow in real time, a set of paired measurements is performed using a real-time velocity meter (e.g., a hot-wire anemometer) at the same time that an EPA flow measurement is made. There will be slight differences in the two measurements, since the real-time velocity meter typically will only measure air velocity at a single point, whereas the EPA method measures average velocity over the entire duct. A conversion factor is developed to translate the single-point velocity measurement to a full-duct EPA measurement. Additional conversion factors are developed to correct for linear velocity to volumetric flow and to correct for ambient pressure and temperature conditions. Also, the real-time meter is adjusted to account for the possible uncertainty in the real-time readings. These corrections are summarized in the next section. When starting with a real-time, single-point air velocity measurement, the end result of applying these correction factors will be a determination of actual exhaust air flow in the FTWC ventilation duct.

The flow meter selected for this operation is the Sierra Instruments 620s. This instrument is a hot-wire anemometer that reads out in standard feet per minute air velocity. While the instrument readout can be adjusted for various settings, it was desired to simplify the instrument's operation and perform all corrections after-the-fact, leaving the instrument electronics untouched. The instrument is calibrated with standard conditions being defined as: $T_{std} = 70^\circ \text{ F}$; $P_{std} = 1 \text{ atmosphere}$.

⁷ Title 40, Code of Federal Regulation, Part 60, Standards of Performance for New Stationary Sources. Appendix A-1 to Part 60, Test Methods 1 through 2F. Incorporated into LANL site procedure ENV-ES-QP-127, R7.

2.1 Correction for meter uncertainty.

The Sierra Instruments 620s selected for use has a factory full-scale setting of 7500 feet per minute, and an associated factory uncertainty of 1% of full scale; this corresponds to 75 feet per minute. Therefore, all measurements made by the Sierra meter will be reduced by this amount to provide a conservative reading. These instruments are then calibrated by LANL-approved vendors; the LANL calibration verified the accuracy of the factory settings, as a “limited” calibration over a subset of flow ranges (300-3056 standard cubic feet per minute).

The minimum air velocity associated with any given reading on the Sierra 620s is as follows:

$$v_{min} = v_{inst} - v_{unc}$$

(Equation 7)

Where:

v_{min} = minimum air velocity, standard feet per minute; this is the minimum air velocity that could exist for a given instrument reading

v_{inst} = instrument readout on display of Sierra 620s, in standard feet per minute

v_{unc} = calibration uncertainty (tolerance) of instrument, 75 std. feet per minute

2.2 Area correction: converting velocity to flow rate.

The Sierra 620s meter reads out in standard linear feet per minute air velocity. To convert from linear velocity to a volumetric flow rate, one simply multiplies the velocity by the cross-sectional area of the duct. The duct is a uniform round 10” diameter duct.

$$A_{duct} = \pi * \frac{(D_{duct})^2}{4}$$

(Equation 8)

$$\dot{V}_{std} = v_{min} * A_{duct}$$

(Equation 9)

Where:

A_{duct} = cross sectional area of duct, 0.5454 square feet

D_{duct} = diameter of duct, 10 inches = 0.833 feet

\dot{V}_{std} = volumetric air flow at standard conditions, standard cubic feet per minute

v_{min} = air velocity, corrected for instrument uncertainty; standard feet per minute

2.3 Correction from standard conditions to actual ambient conditions.

As detailed in Section 1.2, the corrections from standard conditions to actual conditions are given by the equation below.

$$\dot{V}_{act} = \dot{V}_{std} * \left(\frac{T_{act}}{T_{std}} \right) * \left(\frac{P_{std}}{P_{act}} \right)$$

(Equation 10)

Where:

P_{std} , T_{std} , and \dot{V}_{std} = Pressure, temperature, and volumetric flow of a given quantity of gas at standard conditions;

$T_{std} = 70^{\circ} \text{ F} = 529.67 \text{ Rankine}$

$P_{std} = 1 \text{ atmosphere} = 1013.25 \text{ millibars}$

P_{act} , T_{act} , and \dot{V}_{act} = Pressure, temperature, and volumetric flow of a given quantity of gas at actual conditions at the time of measurement

In the attached calculations, these conversions are typically separated into two independent corrections – a temperature correction and a pressure correction. This simplifies error checking and understanding.

The temperature correction term is a ratio of the actual air temperature in the exhaust duct to standard temperature. When calculating the temperature correction, the standard and actual temperatures must both be in units based on absolute zero, i.e. Kelvin or Rankine scale. The Sierra 620s assumes a standard temperature of 70° Fahrenheit, or 529.67 Rankine.

The pressure correction is simply a ratio of the standard air pressure to the ambient air pressure, in consistent units; this pressure correction is typically about 1.3. Note that LANL's meteorology program records air pressure in millibars while the Stacks database uses inches of mercury; one atmosphere is equal to 1013.25 millibars or 29.92 inches of mercury. Typical air pressure at LANL elevation is about 0.77 atmospheres, or 780 millibars or 23.04 inches of mercury.

Given the relationships above, it is clear that the actual flow rate will vary directly with temperature and inversely with pressure; e.g., lower temperatures give lower flow rates, while higher pressures give lower flow rates. Since the goal is to ensure a minimum level of actual flow in the duct, the most conservative bounding case will use the lowest temperature anticipated and the highest ambient pressure that can be reasonably anticipated for the FTWC venting operation. This bounding condition is described in Section 2.6.

When determining ambient pressure, the typical method used by the Stacks database is to reference ambient air pressure using one of the LANL weather towers, either at TA-6 or TA-54. To adjust these tower readings for elevation differences between the tower location and the field measurement location, LANL uses a standard adjustment of -0.1 inch of mercury change for every 100 feet of increased elevation. This corresponds to 3.4 millibars of pressure for every 100 feet of elevation change, with decreasing pressure as elevation increases. Data supporting this elevation change correction appears in Section 4.1 of this document.

2.4 Correction for single-point measurement correction.

To convert a single-point measurement to a full-area average velocity, RAEM team personnel performed a series of EPA flow measurements covering a variety of possible flow configurations. A Sierra 620s real-time velocity meter was installed in the duct, and readings from the Sierra 620s were taken concurrently with the EPA full-profile measurements. The Sierra 620s was new and within its factory NIST certification, but had not yet been through the LANL Standards and Calibration program certification.

The EPA traverse measurements are entered into the EPC-CP “Stacks” database; output from this database is shown in Table 1 below, paired with the real-time Sierra 620s readings.

Table 1: Comparison of EPA flow measurement results to real-time instrument readings						
Profile- Config	EPA Method 2		Sierra 620s Real-time velocity meter			Ratio, EPA vel. to avg_Sierra
	actual flow: actual ft ³ /min	std velocity: std ft/min	low / high / <u>avg</u> std ft/min	Range sfpm	Vari- ability	
02 – 24	2230 acfm	3175	3403 / 3488 / <u>3446</u>	85	2.5%	92.1%
02 – 32	1605 acfm	2284	2501 / 2568 / <u>2535</u>	67	2.6%	90.1%
02 – 48	1617 acfm	2301	2528 / 2569 / <u>2549</u>	41	1.6%	90.3%
01 – 48	1294 acfm	1851	1636 / 1670 / <u>1653</u>	34	2.1%	112%

In Table 1, the “Profile – Config” column indicates which blower is used and the configuration the FTWC duct. Profile 01 is the smaller ¾ horsepower blower, and Profile 02 is the larger 2 HP blower. The Configuration number is the length of flex duct attached to the end of the rigid duct. Different configurations were tested to ensure sufficient flow could be achieved in the duct.

These data in Table 1 are documented in the Stacks database measurement reports. The Sierra 620s readings were observations made on the meter during the EPA flow test; the average value used in the ratio calculations is simply the

numerical average of the highest and lowest reading observed. This calculated average value compares well with the estimated average velocity made during the flow measurements. Using the calculated average for the Sierra 620s reading is the most reasonable method given the field constraints of the flow testing.

Table 1 also shows the range of the Sierra 620s readings for each test (high value minus the low value), and the variability of the velocity reading, which is this range divided by the average reading.

The four Stacks database reports summarized above are included in Section 4.2 of this document. The comment section of each report shows the Sierra 620s readings; the high, low, and user-estimated average of the instrument.

The final column of Table 1 is the ratio of duct velocity measured using EPA methods to the calculated average velocity measured by the Sierra 620s. Based on these observations, a conservative correction factor of 90% will be used to convert the single point velocity measurement to the average velocity over the full cross-sectional area of the duct.

$$C_{SP} = 90\%$$

(Equation 11)

Where:

C_{SP} = Correction factor converting a single point measurement to the average velocity over the full cross sectional area of the duct

2.5 Final flow correction equation

Combining terms in sections 2.1 through 2.4, one ends with the following equation:

$$\dot{V}_{act} = (v_{inst} - v_{unc}) * A_{duct} * \left(\frac{T_{act}}{T_{std}}\right) * \left(\frac{P_{std}}{P_{act}}\right) * C_{SP}$$

(Equation 12)

Where:

\dot{V}_{act} = Actual volumetric flow rate through the FTWC exhaust duct, actual cubic feet per minute (acfm or actual ft³/min)

v_{inst} = velocity real-time reading of the Sierra 620s instrument; standard feet per minute (sfpm)

v_{unc} = Uncertainty/tolerance of Sierra 620s; 75 standard feet per minute

A_{duct} = Cross-sectional area of the FTWC exhaust duct; 0.5454 square feet (ft²)

P_{std} and T_{std} = Pressure and temperature at standard conditions;

$T_{std} = 70^{\circ} \text{ F} = 529.67 \text{ Rankine}$

$P_{std} = 1 \text{ atmosphere} = 1013.25 \text{ millibars} = 29.92 \text{ inches of mercury}$

P_{act} and T_{act} = Actual pressure and temperature at ambient conditions at the time of measurement; units must be converted to match standard conditions above

C_{SP} = Correction factor converting a single point measurement to the average velocity over the full cross sectional area of the duct; 90% (unitless)

This equation above can be used for any operating environment encountered during FTWC venting operations.

2.6 Correction equation for bounding conditions

The master correction equation in Section 2.5 can be used as a worst-case scenario for the bounding conditions established for the FTWC venting project.

$$\dot{V}_{limit} = (v_{inst} - v_{unc}) * A_{duct} * \left(\frac{T_{bound}}{T_{std}} \right) * \left(\frac{P_{std}}{P_{bound}} \right) * C_{SP}$$

(Equation 13)

Where all variables are identical to Section 2.5, with the following changes:

P_{bound} = Worst-case pressure; 5-year maximum pressure as measured at any LANL meteorological tower⁸;

$P_{bound} = 0.8043 \text{ atmosphere} = 815 \text{ millibars} = 24.07 \text{ inches of mercury}$

T_{bound} = Worst-case temperature; the lowest conditions at which venting operations would be performed to meet instrument requirements.

$T_{bound} = 32^{\circ} \text{ F} = 491.67 \text{ Rankine}$

\dot{V}_{limit} = limiting flow rate for each blower system, actual cubic feet per minute

Using these bounding parameters, one can simply set the desired \dot{V}_{limit} to the desired flow rate in section 1.2 and then solve for the required minimum instrument reading on the Sierra 620s.

⁸ Maximum air pressure determined from data download from LANL Weather Machine. Data range 12/21/2014 through 12/19/2019. Excel file in Rad-NESHAP files, "ta54_AirPressure_5yr.xlsx"

$$v_{inst} = \left[\frac{\dot{V}_{limit}}{C_{SP} * A_{duct}} * \frac{T_{std}}{T_{bound}} * \frac{P_{bound}}{P_{std}} \right] + v_{unc}$$

(Equation 14)

For using the large 2HP blower for venting FTWCs at TA-54 Area G, the limiting flow rate is 1476 acfm; the resulting Sierra 620s reading must be at least 2680 sfpm.

$$v_{inst,2HP} = \left[\frac{1476 \text{ actual } ft^3/min}{90\% * 0.5454 ft^2} * \frac{529.67 R}{491.67 R} * \frac{0.8043 atm}{1 atm} \right] + 75 \text{ std } \frac{ft}{min} = 2680 \text{ std } \frac{ft}{min}$$

(Equation 15)

For using the smaller ¾ HP blower for venting FTWCs outside of Area G, the limiting flow rate is 753 acfm; the resulting Sierra 620s reading must be at least 1404 sfpm.

$$v_{inst,3/4HP} = \left[\frac{753 \text{ actual } ft^3/min}{90\% * 0.5454 ft^2} * \frac{529.67 R}{491.67 R} * \frac{0.8043 atm}{1 atm} \right] + 75 \text{ std } \frac{ft}{min} = 1404 \text{ std } \frac{ft}{min}$$

(Equation 16)

A plot showing the correlation between Sierra 620s meter reading and actual flow rate at these bounding conditions is shown in Figure 1. For the small blower, the reading on the Sierra 620s should be to the right of the red box, greater than 1404 std ft/min. For the large blower, the Sierra 620s reading should be to the right of the gold box, greater than 2680 std ft/min. As long as the air velocity indicated on the Sierra 620s is higher than these values, there is sufficient flow in the FTWC exhaust duct for all possible operational conditions.

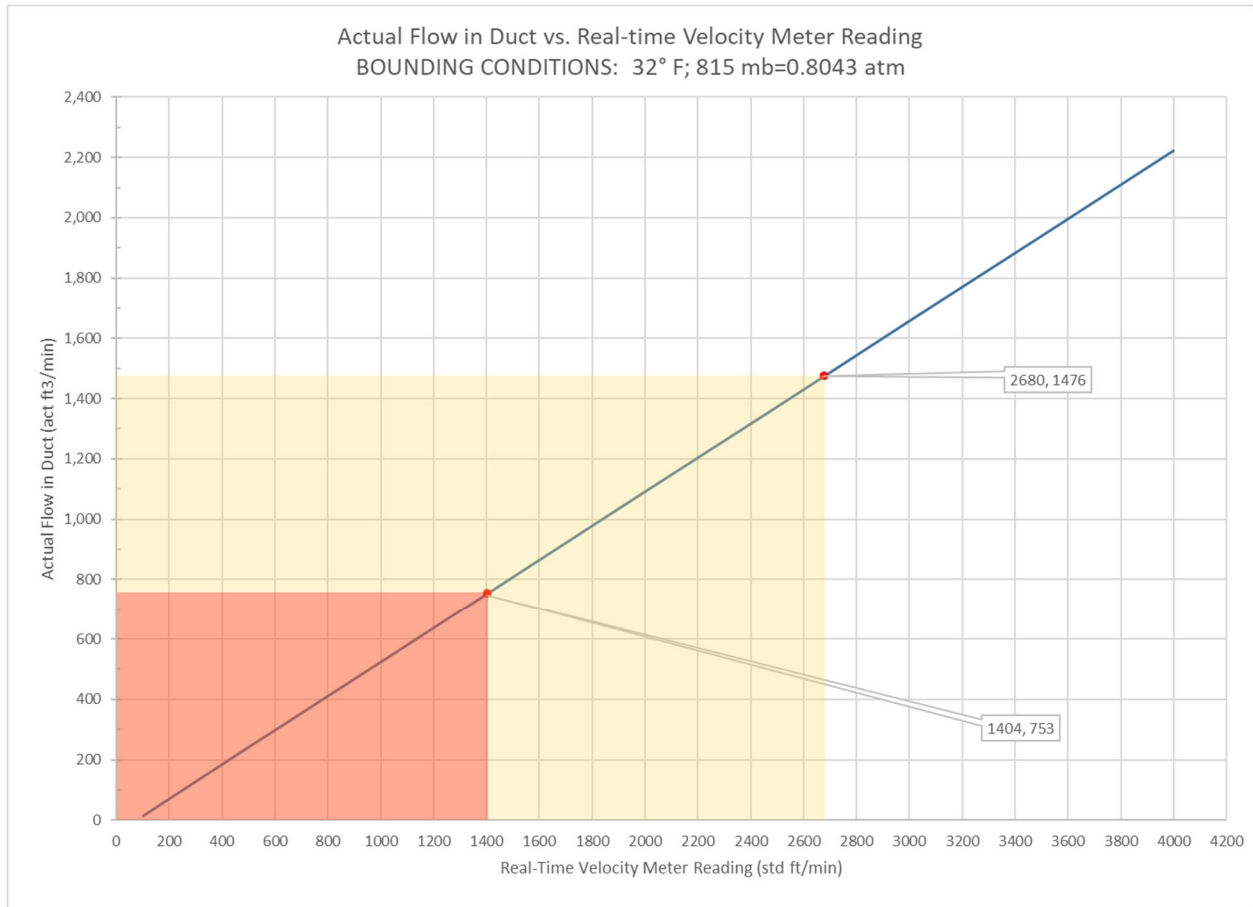


Figure 1: Actual Duct Flow vs. Sierra 620s Reading for Bounding Conditions

2.7 Determining if sufficient flow exists in the FTWC exhaust duct

As mentioned, the master flow correction equation in Section 2.5 can be used for any operating scenario encountered during FTWC venting operations.

Actual duct flow can be determined from the master flow correction equation in Section 2.5, given ambient conditions encountered that day.

$$\dot{V}_{act} = (v_{inst} - v_{unc}) * A_{duct} * \left(\frac{T_{act}}{T_{std}} \right) * \left(\frac{P_{std}}{P_{act}} \right) * C_{SP}$$

(Equation 17; identical to Equation 12)

Replacing variables with known values, and expressing temperature in Rankine, pressure in millibars, and the Sierra 620s instrument reading in standard feet per minute, the actual duct flow in actual cubic feet per minute is calculated using the equation below:

$$\dot{V}_{act} = \left(v_{inst} - 75 \text{ std } \frac{ft}{min} \right) * 0.5454 \text{ ft}^2 * \left(\frac{T_{act}}{529.67^\circ R} \right) * \left(\frac{1013.25 \text{ mbar}}{P_{act}} \right) * 90\%$$

(Equation 18)

Where:

\dot{V}_{act} = Actual volumetric flow rate through the FTWC exhaust duct, actual cubic feet per minute (acfm or actual ft³/min)

v_{inst} = velocity real-time reading of the Sierra 620s instrument; standard feet per minute (sfpm)

v_{unc} = Uncertainty/tolerance of Sierra 620s; 75 standard feet per minute

A_{duct} = Cross-sectional area of the FTWC exhaust duct; 0.5454 square feet (ft²)

P_{std} and T_{std} = Pressure and temperature at standard conditions;

$T_{std} = 70^\circ \text{ F} = 529.67 \text{ Rankine}$

$P_{std} = 1 \text{ atmosphere} = 1013.25 \text{ millibars} = 29.92 \text{ inches of mercury}$

P_{act} and T_{act} = Actual pressure and temperature at ambient conditions at the time of measurement; units must be converted to match standard conditions above

C_{SP} = Correction factor converting a single point measurement to the average velocity over the full cross sectional area of the duct; 90% (unitless)

Reorganizing the master flow correction equation from Section 2.5, the minimum reading on the Sierra 620s meter can be determined from the actual ambient conditions and the required minimum duct flow rates.

$$v_{inst} = \left[\frac{\dot{V}_{limit}}{C_{SP} * A_{duct}} * \frac{T_{std}}{T_{act}} * \frac{P_{act}}{P_{std}} \right] + v_{unc}$$

(Equation 19; identical to Equation 14)

Replacing variables with known values, and expressing temperature in Rankine, pressure in millibars, and instrument reading in standard feet per minute, this equation is now:

$$v_{inst} = \left[\frac{\dot{V}_{limit}}{90\% * 0.5454 \text{ ft}^2} * \frac{529.67^\circ R}{T_{act}} * \frac{P_{act}}{1013.25 \text{ mbar}} \right] + 75 \text{ std } \frac{ft}{min}$$

(Equation 20)

For use of the large 2HP blower at TA-54 Area G; the limiting flow rate is 1476 actual cubic feet per minute. The resulting equation for minimum reading on the Sierra 620s in standard feet per minute is:

$$v_{inst,2HP} = \left[\frac{1476 \text{ actual } \frac{ft^3}{min}}{90\% * 0.5454 ft^2} * \frac{529.67^\circ R}{T_{act}} * \frac{P_{act}}{1013.25 \text{ mbar}} \right] + 75 \text{ std } \frac{ft}{min}$$

(Equation 21)

For use of the small ¾ HP blower away from TA-54; the limiting flow rate is 753 actual cubic feet per minute. The resulting equation for minimum reading on the Sierra 620s in standard feet per minute is:

$$v_{inst,3/4HP} = \left[\frac{753 \text{ actual } \frac{ft^3}{min}}{90\% * 0.5454 ft^2} * \frac{529.67^\circ R}{T_{act}} * \frac{P_{act}}{1013.25 \text{ mbar}} \right] + 75 \text{ std } \frac{ft}{min}$$

(Equation 22)

3.0 Field Implementation

These equations and methods can be used in the field during FTWC venting operations. Once the proper duct configuration is established, the methods described in Sections 3.2, 3.3, or 3.4 must be used to document the duct flow rate.

3.1 Ensure duct setup

Ensure the duct exhaust train is setup as described in the FTWC venting IWD; this allows use of the methods and relationships defined in this document.

3.2 Bounding scenario

Compare the Sierra 620s reading when the duct is operational to the minimum air velocities described in Section 2.6 and shown in Figure 1. If the Sierra 620s flow exceeds the required value, then sufficient flow exists for venting and no further action is needed. Further steps may be taken if more precise data is desired.

3.3 Ambient conditions calculations

If the Sierra 620s does not indicate sufficient flow in the duct per the bounding conditions in Section 2.6, or if more precise data is desired, use the calculations in Section 2.7 to determine actual flow rate in the duct and actual minimum Sierra 620s conditions for the current atmospheric conditions.

3.4 Full-traverse flow calculation per EPA methods

If sufficient flow is still not indicated on the Sierra 620s, or if more precise data is required, RAEM team members will perform a flow measurement per EPA methods on the installed system. This will provide detail on exact flow rate in the duct for a given setup. This measurement shall be performed per EPC-CP

group procedure 127⁹. If being performed for data refinement, this measurement may be performed at any point during the venting process (e.g., while waiting for FTWC pressure to equilibrate). If needed to document sufficient flow, this procedure shall be performed prior to venting.

Note that full implementation of the procedure uses the Stacks database in EPC-CP; duplication of the database calculations via spreadsheet on a laptop may be done to allow remote calculation of flow rate. **Per RAEM team policy the Stacks database (and other databases used by the team) have the calculations verified annually by hand-checking the database calculations.**

3.5 Documentation

Use the worksheet in **Section 4.3** to document the exhaust flow status of the FTWC venting project. If the worksheet is unavailable, identical information recorded in the FTWC project venting log is sufficient.

4.0 Attachments

- 4.1 Ambient Air Pressure at Different Elevations, 1 page
- 4.2 Stack Flow Measurement Reports, for four flow tests discussed in Section 2.4; each test is 6 pages; 24 pages total
 - 4.2.1 Profile 02, Configuration 24; 2HP blower, rigid duct and 24 ft flex duct
 - 4.2.2 Profile 02, Configuration 32; 2HP blower, rigid duct and 32 ft flex duct
 - 4.2.3 Profile 02, Configuration 48; 2HP blower, rigid duct and 48 ft flex duct
 - 4.2.4 Profile 01, Configuration 48; ¾ HP blower, rigid duct and 48 ft flex duct
- 4.3 Documentation of FTWC Flow Rates, 2 pages
- 4.4 Revision History
- 4.5 Documentation of Peer Review & Calculation Verification

⁹ ENV-ES-QP-127, R7, Determination of Stack Gas Velocity and Flow Rate in Exhaust Stacks, Ducts, and Vents. Jan 23, 2012. On the LANL internal web at: <http://int.lanl.gov/training/env-courses/14084/env-es-qp-127.pdf>

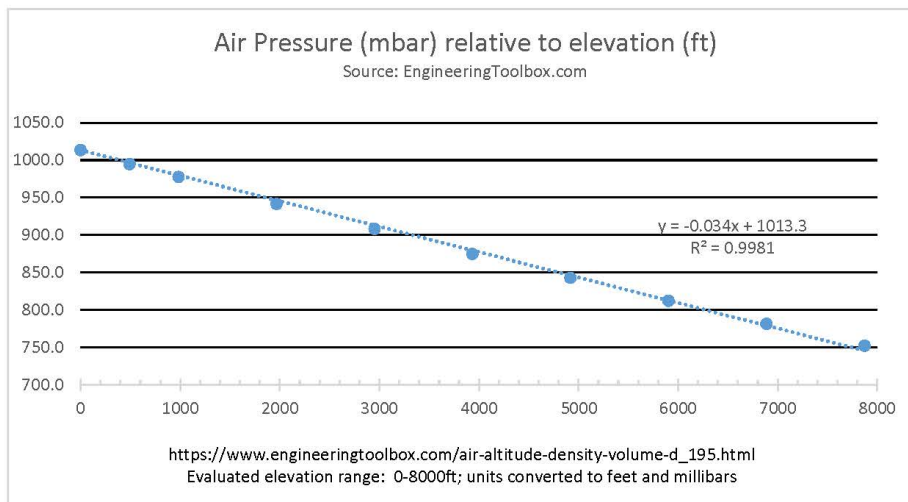
4.1 Ambient Air Pressure at Different Elevations

4.1 Ambient air pressure at different elevations.

Source: https://www.engineeringtoolbox.com/air-altitude-density-volume-d_195.html
Using data from zero to ~8000 feet elevation only.

Elevation (ft)	Air Pressure (mbar)
0	1013.2
492	994.6
984	977.3
1968	941.3
2952	907.9
3936	874.6
4920	842.6
5904	811.9
6888	781.3
7874	751.9

*Website data units are
converted to feet & millibars*



Trendline equation: x = elevation above sea level (ft); y = ambient air pressure (mbar)
 $y = -0.034x + 1013.3$

Every 1-foot increase in elevation results in reduced pressure by 0.034 mbar

Every 100-ft increase in elevation reduces ambient air pressure by 3.4 mbar

This validates Stacks database assumption that 100-ft elevation gain = 0.1" Hg reduction

3.4 mbar = 0.1 inch Hg

LANL barometer elevations:

TA-54 weather station = 6548 ft

TA-6 weather station = 7424 ft

tower data: LA-UR-04-3397

Google Earth estimates of vent site elevations:

TA-54-1028 = 6735 ft; 187 ft above TA-54; -6.4 mbar

TA-16-0205 lot = 7608 ft; 184 ft above TA-6; -6.3 mbar

All analyses: David Fuehne, 12/23/2019

FlowMeterConversionTesting2.xlsx

ComputeKValue

4.2 Stack Flow Measurement Reports

The following pages contain the stack flow measurement reports for tests performed on Dec 3, 2019.

These tests illustrate the relationship between an EPA flow measurement across the full cross-sectional area of the exhaust duct and the single-point velocity reading made by the Sierra 620s instrument.

Each report consists of three sections:

- Form 5M, data entry (shows Sierra 620s reading in comment field); 2 pages
- Individual velocity report (shows actual cfm); 2 pages
- Form 6, flow calculations, with comment fields showing ratio of EPA measurement to Sierra 620s measurement; 2 pages.

Four tested configurations:

- 4.2.1 Profile 02, Configuration 24; large 2HP blower, rigid duct and 24 ft flex duct
- 4.2.2 Profile 02, Configuration 32; large 2HP blower, rigid duct and 32 ft flex duct
- 4.2.3 Profile 02, Configuration 48; large 2HP blower, rigid duct and 48 ft flex duct
- 4.2.4 Profile 01, Configuration 48; small $\frac{3}{4}$ HP blower, rigid duct and 48 ft flex duct

Results from these four tests are summarized earlier in this document in Table 1.

Section 4.2.1

Stack flow measurement report

Flow Profile 02 (2HP blower)

Flow Configuration 24;

Rigid duct + 24 ft flex duct

Ecology and Air Quality

Velocity Measurement Input Form (Form 5-M)

Page 1 of 2

This form is from EAQ-127

TA / Building / ES: 35-0034-FTMeasurement Date: 12/03/2019FE(s): 01Profile Measurement Number: 02Fan Exhaust Configuration: 24☐ Quarterly/semi-annual airflow measurement ☒ Special measurement ☐ Other _____☐ Method 2 (stack or duct diameter ≥ 12 ") ☒ Method 2C (stack or duct diameter ≥ 4 " but < 12 ")**1. Equipment used and verification**Manometer: EDM Serial #: T58251123035 Calibration Expiration: 04/10/2020Thermometer: EDT Serial #: 140738398 Calibration Expiration: 04/15/2020Humidity Meter: THT Serial #: 140738398 Calibration Expiration: 04/15/2020Pitot Tube: Standard Pitot Tube Serial #: STD-18-01☒ Traverse spacing pre-marked on pitot tube / pitot tube inspected**2. Location inspection**

Location comments: Straight, no kinks in the flex duct

3. Equipment setup☒ Zero the manometer ΔP Offset 0.000☒ Connect manometer to tubing☒ Adjust manometer sensitivityPre-test leak check performed (not mandatory) ☐ Yes ☒ No**4. Perform traverse readings** (record velocity pressure in table on appropriate form)Run Start Time: 12:29 PM Run Complete Time: 12:45 PM Average Temperature (Deg F): 62.0**5. Diameter and cross-sectional area of stack or duct (from previous measurements)**Average Diameter (in): 10.000Area (sq ft): 0.545**6. Post measurement leak test (3" wg)**☒ Successful☐ Measurement voided**7. Static Pressure and Relative Humidity**SP = -2.951 inches waterRH = 29%*(RH recorded for historical purposes only.**Not used in calculations. 0% used in calculations)***8. Back purge standard pitot tube and verify**☐ Not RequiredProfile Location: A 03 Original Reading: 0.853 Verify Reading: 0.851 Percent Difference: 0.18%

Velocity Measurement Input Form (Form 5-M)

Page 2 of 2

This form is from EAQ-127

9. Stack gas dry molecular weight

29.0 (Room Air)

10. Condition which might affect measurements

11. Holes covered

☒ complete

12. Atmospheric pressure

22.98 "HgBarometer location: TA-6 Weather StationElevation: 7424

13. Post measurement Verifications

Test Number	Velocity Pressure (inches wg)		
	Manometer	Reference	% Difference
1	0.161	0.160	0.63%
2	0.441	0.440	0.23%
3	0.851	0.850	0.12%

☒ Manometer Verification Passed (within 5%)

Temperature Reading, °F		Absolute Temperature, °R °R = °F + 460		
Thermometer	Reference	Thermometer	Reference	% Difference
67.4	68.0	527.4	528.0	0.12%

☒ Thermometer verification passed (within 1.5%)

General Comments:

Flow meter velocity reading (ft/min): 3403 - 3488, ~3440

**Average of low & high readings is 3446 standard feet per minute.
This average value used in later calculations.**

Flow measurements were made in accordance with the latest revision of EAQ-127.

Measurements by:

Signature	Lattin, Rebecca	219035	Date
	Print name	Z-Number	

EAQ QA check by:

EAQ review and approval by:

Initials

Original hard copies signed in Rad-NESHAP records.

Stack Gas Velocities (actual) for Individual Velocity Pressure Measurements

TA/Building/ES: 350034FT Fan Exhaust Configuration: 24

Measurement Date: 12/03/2019 FE(s): 01

Profile Measurement Number: 02

Traverse #	Point #	Point Spacing	Velocity Pressure	SQRT(VP)	* Cp *	K	=	Velocity (ft/min)
A	01	1/2	0.756	0.869	0.99	4541		3907
A	02	1	0.778	0.882	0.99	4541		3965
A	03	2	0.853	0.923	0.99	4541		4151
A	04	3-1/4	0.870	0.933	0.99	4541		4193
A	05	6-3/4	0.852	0.923	0.99	4541		4149
A	06	8	0.833	0.912	0.99	4541		4102
A	07	9	0.796	0.892	0.99	4541		4009
A	08	9-1/2	0.750	0.866	0.99	4541		3892
B	01	1/2	0.758	0.870	0.99	4541		3913
B	02	1	0.846	0.920	0.99	4541		4135
B	03	2	0.911	0.954	0.99	4541		4290
B	04	3-1/4	0.883	0.939	0.99	4541		4223
B	05	6-3/4	0.893	0.945	0.99	4541		4248
B	06	8	0.923	0.960	0.99	4541		4318
B	07	9	0.826	0.909	0.99	4541		4086
B	08	9-1/2	0.726	0.852	0.99	4541		3830

Stack Gas Velocities (actual) for Individual Velocity Pressure Measurements

TA/Building/ES: 350034FT Fan Exhaust Configuration: 24
Measurement Date: 12/03/2019 FE(s): 01
Profile Measurement Number: 02

Average stack gas velocity (actual), vs: 4088 ft/min
Exhaust stack flow rate (actual), Q: 2230 acfm
Velocity coefficient of variation (COV): 2.56%
(for center 2/3 of stack area)
Stack type: 2 * 8 Round Stack or Duct
Traverse points eliminated in 2/3 area COV calculation: 01, 08

Data Entered by:

Signature

Data QAed by:

Signature

Measurement Approved

Original hard copies signed in Rad-NESHAP records.

Signature

Print name

Z-Number

Date

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Flow Measurement Calculation Form (Form 6)

Page 1 of 2

This form is from EAQ-127

TA/Building/ES:	350034FT	Fan Exhaust Configuration:	24
Measurement Date:	12/03/2019	FE(s):	01
Profile Measurement Number:	02		

Step 1: Calculate the Stack gas average absolute temperature, Ts(avg)

- a) From field input form, determine ts(avg) = 62.0 ° F
- b) Calculate the absolute temperature, Ts(avg) = ts(avg) + 460 = 522.0 ° R

Step 2: Calculate the exhaust stack absolute pressure, Ps

- a) From field input form, record the barometric reference pressure, Pref = 22.98 "Hg
- b) Adjusting for elevation,
- $$Pbar = Pref + (Elevation[profile] - Elevation[ref]) * (-0.1 \text{ "Hg/100 ft})$$
- $$= 22.98 + (7217.0 - 7424) * (-0.1 \text{ "Hg/100 ft})$$
- $$= \underline{23.187} \text{ "Hg}$$
- c) From field input form, record the static stack pressure, Pg = -2.951 "wg
- d) Convert the static stack pressure from inches w.g. to inches Hg:
- $$Pg = [Pg \text{ "wg}] * (62.4/846.9) \text{ "Hg}$$
- $$= 2.951 * (62.4/846.9) \text{ "Hg}$$
- $$= \underline{-0.217} \text{ "Hg}$$
- e) Calculate the exhaust stack absolute pressure:
- $$Ps = Pbar + Pg$$
- $$= 23.187 + -0.217 = \underline{22.970} \text{ "Hg}$$

Step 3: Calculate the molecular weight of the stack gas, Ms

- a) From Method 4 or 5: Bws = 0 (Use 0 for dry air)
- b) From Method 3: Md = 29 (Use 29 for dry air)
- c) Calculate Ms:
- $$Ms = (Md * (1 - Bws)) + (18.0 * Bws)$$
- $$= (29 * (1 - 0)) + (18.0 * 0)$$
- $$= \underline{29} \text{ lb/lb mole}$$

Flow Measurement Calculation Form (Form 6)

Page 2 of 2

This form is from EAQ-127

Step 4: Calculate K

$$a) \quad K = (85.49) * (60) * \sqrt{\frac{T_{s(avg)}}{P_s * M_s}}$$

$$= (85.49) * (60) * \text{SQRT}(522.0 / (22.970 * 29)) = \underline{4541}$$

Step 5: From the field input form, calculate the average velocity head of the stack gas

$$a) \quad (\sqrt{\Delta p})_{avg} = \frac{\sum_{i=1}^n \sqrt{\Delta p}}{n} = \underline{0.909} \text{ inches water}$$

Step 6: Calculate the average stack gas velocity (actual), vs

$$a) \quad v_s = C_p * K * (\sqrt{\Delta p})_{avg} \text{ ft/min}$$

$$= 0.99 * 4541 * 0.909$$

$$= \underline{4088.155} \text{ ft/min} \quad \text{multiply by T and P below; result = 3174.6 std ft/min}$$

Step 7: Calculate the exhaust stack flow rate (actual), Q

a) Record the stack/duct cross-sectional area from profile measurements

$$A = 0.545 \text{ sq ft}$$

b) Q = vs * A

$$= 4088.155 * 0.545$$

$$= \underline{2230} \text{ acfm}$$

Single Point correction ratio:

Overall velocity reading
(above) divided by Avg Sierra
620s reading (earlier):

$$3175 / 3446 = \underline{92.1\%}$$

D. Fuehne, 12/23/2019

Step 8: Calculate the exhaust stack gas dry volumetric flow rate (standard), Qsd

$$a) \quad Q_{sd} = (1 - B_{ws}) * v_s * A * \frac{T_{std}}{T_{s(avg)}} * \frac{P_s}{P_{std}}$$

$$= (1 - 0) * 4088.155 * 0.545 * \frac{528}{522.0} * \frac{22.970}{29.92}$$

$$= \underline{1731} \text{ scfm}$$

T
temp
correction
= 1.011

P
pressure
correction
= 0.768

Section 4.2.2

Stack flow measurement report
Flow Profile 02 (2HP blower)
Flow Configuration 32;
Rigid duct + 32 ft flex duct

Ecology and Air Quality

Velocity Measurement Input Form (Form 5-M)

Page 1 of 2

This form is from EAQ-127

TA / Building / ES: 35-0034-FTMeasurement Date: 12/03/2019FE(s): 01 Profile Measurement Number: 02 Fan Exhaust Configuration: 32☐ Quarterly/semi-annual airflow measurement ☒ Special measurement ☐ Other _____☐ Method 2 (stack or duct diameter ≥ 12 ") ☒ Method 2C (stack or duct diameter ≥ 4 " but < 12 ")**1. Equipment used and verification**Manometer: EDM Serial #: T58251123035 Calibration Expiration: 04/10/2020Thermometer: EDT Serial #: 140738398 Calibration Expiration: 04/15/2020Humidity Meter: THT Serial #: 140738398 Calibration Expiration: 04/15/2020Pitot Tube: Standard Pitot Tube Serial #: STD-18-01☒ Traverse spacing pre-marked on pitot tube / pitot tube inspected**2. Location inspection**

Location comments: bend around twice the width of the recycling bin

3. Equipment setup☒ Zero the manometer ΔP Offset 0.000☒ Connect manometer to tubing ☒ Adjust manometer sensitivityPre-test leak check performed (not mandatory) ☐ Yes ☒ No**4. Perform traverse readings** (record velocity pressure in table on appropriate form)Run Start Time: 1:13 PM Run Complete Time: 1:27 PM Average Temperature (Deg F): 62.0**5. Diameter and cross-sectional area of stack or duct (from previous measurements)**Average Diameter (in): 10.000 Area (sq ft): 0.545**6. Post measurement leak test (3" wg)**☒ Successful ☐ Measurement voided**7. Static Pressure and Relative Humidity**SP = -2.892 inches water RH = 29% *(RH recorded for historical purposes only. Not used in calculations. 0% used in calculations)***8. Back purge standard pitot tube and verify** ☐ Not RequiredProfile Location: B 06 Original Reading: 0.492 Verify Reading: 0.494 Percent Difference: 0.40%

Velocity Measurement Input Form (Form 5-M)

Page 2 of 2

This form is from EAQ-127

9. Stack gas dry molecular weight

29.0 (Room Air)

10. Condition which might affect measurements

11. Holes covered

☒ complete

12. Atmospheric pressure

22.97 "HgBarometer location: TA-6 Weather StationElevation: 7424

13. Post measurement Verifications

Test Number	Velocity Pressure (inches wg)		
	Manometer	Reference	% Difference
1	0.161	0.160	0.63%
2	0.441	0.440	0.23%
3	0.851	0.850	0.12%

☒ Manometer Verification Passed (within 5%)

Temperature Reading, °F		Absolute Temperature, °R °R = °F + 460		
Thermometer	Reference	Thermometer	Reference	% Difference
67.4	68.0	527.4	528.0	0.12%

☒ Thermometer verification passed (within 1.5%)

General Comments:

Flow meter velocity reading (ft/min): 2501 - 2568, ~2530

**Average of low & high readings is 2535 standard feet per minute.
This average value used in later calculations.**

Flow measurements were made in accordance with the latest revision of EAQ-127.

Measurements by:

Signature	Lattin, Rebecca	219035	Date
	Print name	Z-Number	

EAQ QA check by:

EAQ review and approval by:

Initials

Original hard copies signed in Rad-NESHAP records.

Stack Gas Velocities (actual) for Individual Velocity Pressure Measurements

TA/Building/ES: 350034FT Fan Exhaust Configuration: 32

Measurement Date: 12/03/2019 FE(s): 01

Profile Measurement Number: 02

Traverse #	Point #	Point Spacing	Velocity Pressure	SQRT(VP)	* Cp *	K	=	Velocity (ft/min)
A	01	1/2	0.347	0.589	0.99	4541		2647
A	02	1	0.385	0.620	0.99	4541		2788
A	03	2	0.426	0.652	0.99	4541		2933
A	04	3-1/4	0.456	0.675	0.99	4541		3034
A	05	6-3/4	0.491	0.700	0.99	4541		3149
A	06	8	0.458	0.676	0.99	4541		3041
A	07	9	0.446	0.667	0.99	4541		3001
A	08	9-1/2	0.409	0.640	0.99	4541		2875
B	01	1/2	0.385	0.620	0.99	4541		2788
B	02	1	0.411	0.641	0.99	4541		2881
B	03	2	0.448	0.669	0.99	4541		3008
B	04	3-1/4	0.459	0.677	0.99	4541		3046
B	05	6-3/4	0.496	0.704	0.99	4541		3166
B	06	8	0.492	0.701	0.99	4541		3154
B	07	9	0.439	0.663	0.99	4541		2979
B	08	9-1/2	0.333	0.577	0.99	4541		2593

Stack Gas Velocities (actual) for Individual Velocity Pressure Measurements

TA/Building/ES: 350034FT Fan Exhaust Configuration: 32
Measurement Date: 12/03/2019 FE(s): 01
Profile Measurement Number: 02

Average stack gas velocity (actual), vs: 2943 ft/min
Exhaust stack flow rate (actual), Q: 1605 acfm
Velocity coefficient of variation (COV): 3.74%
(for center 2/3 of stack area)
Stack type: 2 * 8 Round Stack or Duct
Traverse points eliminated in 2/3 area COV calculation: 01, 08

Data Entered by:

Signature

Data QAed by:

Signature

Measurement Approved

Signature

Print name

Z-Number

Date

Original hard copies signed in Rad-NESHAP records.

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Flow Measurement Calculation Form (Form 6)

Page 1 of 2

This form is from EAQ-127

TA/Building/ES:	350034FT	Fan Exhaust Configuration:	32
Measurement Date:	12/03/2019	FE(s):	01
Profile Measurement Number:	02		

Step 1: Calculate the Stack gas average absolute temperature, Ts(avg)

- a) From field input form, determine ts(avg) = 62.0 °F
- b) Calculate the absolute temperature, Ts(avg) = ts(avg) + 460 = 522.0 °R

Step 2: Calculate the exhaust stack absolute pressure, Ps

- a) From field input form, record the barometric reference pressure, Pref = 22.97 "Hg
- b) Adjusting for elevation,
- $$Pbar = Pref + (Elevation[profile] - Elevation[ref]) * (-0.1 \text{ "Hg/100 ft})$$
- $$= 22.97 + (7217.0 - 7424) * (-0.1 \text{ "Hg/100 ft})$$
- $$= \underline{23.177} \text{ "Hg}$$
- c) From field input form, record the static stack pressure, Pg = -2.892 "wg
- d) Convert the static stack pressure from inches w.g. to inches Hg:
- $$Pg = [Pg \text{ "wg}] * (62.4/846.9) \text{ "Hg}$$
- $$= 2.892 * (62.4/846.9) \text{ "Hg}$$
- $$= \underline{-0.213} \text{ "Hg}$$
- e) Calculate the exhaust stack absolute pressure:
- $$Ps = Pbar + Pg$$
- $$= 23.177 + -0.213 = \underline{22.964} \text{ "Hg}$$

Step 3: Calculate the molecular weight of the stack gas, Ms

- a) From Method 4 or 5: Bws = 0 (Use 0 for dry air)
- b) From Method 3: Md = 29 (Use 29 for dry air)
- c) Calculate Ms:
- $$Ms = (Md * (1 - Bws)) + (18.0 * Bws)$$
- $$= (29 * (1 - 0)) + (18.0 * 0)$$
- $$= \underline{29} \text{ lb/lb mole}$$

Flow Measurement Calculation Form (Form 6)

Page 2 of 2

This form is from EAQ-127

Step 4: Calculate K

$$a) \quad K = (85.49) * (60) * \sqrt{\frac{T_{s(avg)}}{P_s * M_s}}$$

$$= (85.49) * (60) * \text{SQRT}(522.0 / (22.964 * 29)) = \underline{4541}$$

Step 5: From the field input form, calculate the average velocity head of the stack gas

$$a) \quad (\sqrt{\Delta p})_{avg} = \frac{\sum_{i=1}^n \sqrt{\Delta p}}{n} = \underline{0.654} \text{ inches water}$$

Step 6: Calculate the average stack gas velocity (actual), vs

$$a) \quad v_s = C_p * K * (\sqrt{\Delta p})_{avg} \text{ ft/min}$$

$$= 0.99 * 4541 * 0.654$$

$$= \underline{2942.556} \text{ ft/min} \quad \text{multiply by T and P below; result = 2284.4 std ft/min}$$

Step 7: Calculate the exhaust stack flow rate (actual), Q

a) Record the stack/duct cross-sectional area from profile measurements

$$A = 0.545 \text{ sq ft}$$

b) Q = vs * A

$$= 2942.556 * 0.545$$

$$= \underline{1605} \text{ acfm}$$

Single Point correction ratio:

Overall velocity reading
(above) divided by Avg Sierra
620s reading (earlier):

$$2284 / 2535 = \underline{90.1\%}$$

D. Fuehne, 12/23/2019

Step 8: Calculate the exhaust stack gas dry volumetric flow rate (standard), Qsd

$$a) \quad Q_{sd} = (1 - B_{ws}) * v_s * A * \frac{T_{std}}{T_{s(avg)}} * \frac{P_s}{P_{std}}$$

$$= (1 - 0) * 2942.556 * 0.545 * \frac{528}{522.0} * \frac{22.964}{29.92}$$

$$= \underline{1246} \text{ scfm}$$

T
temp
correction
= 1.011

P
pressure
correction
= 0.768

Section 4.2.3**Stack flow measurement report****Flow Profile 02 (2HP blower)****Flow Configuration 48;****Rigid duct + 48 ft flex duct**

Ecology and Air Quality

Velocity Measurement Input Form (Form 5-M)

Page 1 of 2

This form is from EAQ-127

TA / Building / ES: 35-0034-FTMeasurement Date: 12/03/2019FE(s): 01 Profile Measurement Number: 02 Fan Exhaust Configuration: 48☐ Quarterly/semi-annual airflow measurement ☒ Special measurement ☐ Other _____☐ Method 2 (stack or duct diameter ≥ 12 ") ☒ Method 2C (stack or duct diameter ≥ 4 " but < 12 ")**1. Equipment used and verification**Manometer: EDM Serial #: T58251123035 Calibration Expiration: 04/10/2020Thermometer: EDT Serial #: 140738398 Calibration Expiration: 04/15/2020Humidity Meter: THT Serial #: 140738398 Calibration Expiration: 04/15/2020Pitot Tube: Standard Pitot Tube Serial #: STD-18-01☒ Traverse spacing pre-marked on pitot tube / pitot tube inspected**2. Location inspection**Location comments: One large U-turn**3. Equipment setup**☒ Zero the manometer ΔP Offset 0.000☒ Connect manometer to tubing ☒ Adjust manometer sensitivityPre-test leak check performed (not mandatory) ☐ Yes ☒ No**4. Perform traverse readings** (record velocity pressure in table on appropriate form)Run Start Time: 1:37 PM Run Complete Time: 1:51 PM Average Temperature (Deg F): 62.0**5. Diameter and cross-sectional area of stack or duct (from previous measurements)**Average Diameter (in): 10.000 Area (sq ft): 0.545**6. Post measurement leak test (3" wg)**☒ Successful ☐ Measurement voided**7. Static Pressure and Relative Humidity**SP = -2.871 inches water RH = 29% *(RH recorded for historical purposes only. Not used in calculations. 0% used in calculations)***8. Back purge standard pitot tube and verify** ☐ Not RequiredProfile Location: A 05 Original Reading: 0.499 Verify Reading: 0.496 Percent Difference: 0.50%

Velocity Measurement Input Form (Form 5-M)

Page 2 of 2

This form is from EAQ-127

9. Stack gas dry molecular weight

29.0 (Room Air)

10. Condition which might affect measurements

11. Holes covered

☒ complete

12. Atmospheric pressure

22.97 "HgBarometer location: TA-6 Weather StationElevation: 7424

13. Post measurement Verifications

Test Number	Velocity Pressure (inches wg)		
	Manometer	Reference	% Difference
1	0.161	0.160	0.63%
2	0.441	0.440	0.23%
3	0.851	0.850	0.12%

☒ Manometer Verification Passed (within 5%)

Temperature Reading, °F		Absolute Temperature, °R °R = °F + 460		
Thermometer	Reference	Thermometer	Reference	% Difference
67.4	68.0	527.4	528.0	0.12%

☒ Thermometer verification passed (within 1.5%)

General Comments:

Flow meter velocity reading (ft/min): 2528 - 2569, ~2545

**Average of low & high readings is 2549 standard feet per minute.
This average value used in later calculations.**

Flow measurements were made in accordance with the latest revision of EAQ-127.

Measurements by:

Signature	Lattin, Rebecca	219035	Date
	Print name	Z-Number	

EAQ QA check by:

EAQ review and approval by:

Initials

Original hard copies signed in Rad-NESHAP records.

Stack Gas Velocities (actual) for Individual Velocity Pressure Measurements

TA/Building/ES: 350034FT Fan Exhaust Configuration: 48

Measurement Date: 12/03/2019 FE(s): 01

Profile Measurement Number: 02

Traverse #	Point #	Point Spacing	Velocity Pressure	SQRT(VP)	* Cp *	K	=	Velocity (ft/min)
A	01	1/2	0.376	0.613	0.99	4541		2755
A	02	1	0.385	0.620	0.99	4541		2788
A	03	2	0.437	0.661	0.99	4541		2972
A	04	3-1/4	0.461	0.679	0.99	4541		3053
A	05	6-3/4	0.499	0.706	0.99	4541		3174
A	06	8	0.477	0.691	0.99	4541		3105
A	07	9	0.439	0.662	0.99	4541		2977
A	08	9-1/2	0.363	0.602	0.99	4541		2709
B	01	1/2	0.334	0.578	0.99	4541		2598
B	02	1	0.409	0.639	0.99	4541		2873
B	03	2	0.459	0.677	0.99	4541		3046
B	04	3-1/4	0.471	0.686	0.99	4541		3084
B	05	6-3/4	0.496	0.704	0.99	4541		3166
B	06	8	0.502	0.709	0.99	4541		3185
B	07	9	0.459	0.677	0.99	4541		3044
B	08	9-1/2	0.416	0.645	0.99	4541		2900

Stack Gas Velocities (actual) for Individual Velocity Pressure Measurements

TA/Building/ES: 350034FT Fan Exhaust Configuration: 48
Measurement Date: 12/03/2019 FE(s): 01
Profile Measurement Number: 02

Average stack gas velocity (actual), vs: 2964 ft/min
Exhaust stack flow rate (actual), Q: 1617 acfm
Velocity coefficient of variation (COV): 3.99%
(for center 2/3 of stack area)
Stack type: 2 * 8 Round Stack or Duct
Traverse points eliminated in 2/3 area COV calculation: 01, 08

Data Entered by:

Signature

Data QAed by:

Signature

Measurement Appro

Signature

Print name

Z-Number

Date

Original hard copies signed in Rad-NESHAP records.

Printed on 12/23/2019 6:40:50 PM

Flow Measurement Calculation Form (Form 6)

Page 1 of 2

This form is from EAQ-127

TA/Building/ES:	350034FT	Fan Exhaust Configuration:	48
Measurement Date:	12/03/2019	FE(s):	01
Profile Measurement Number:	02		

Step 1: Calculate the Stack gas average absolute temperature, Ts(avg)a) From field input form, determine ts(avg) = 62.0 °Fb) Calculate the absolute temperature, Ts(avg) = ts(avg) + 460 = 522.0 °R**Step 2: Calculate the exhaust stack absolute pressure, Ps**a) From field input form, record the barometric reference pressure, Pref = 22.97 "Hg

b) Adjusting for elevation,

$$Pbar = Pref + (Elevation[profile] - Elevation[ref]) * (-0.1 \text{ "Hg/100 ft})$$

$$= 22.97 + (7217.0 - 7424) * (-0.1 \text{ "Hg/100 ft})$$

$$= \underline{23.177} \text{ "Hg}$$

c) From field input form, record the static stack pressure, Pg = -2.871 "wg

d) Convert the static stack pressure from inches w.g. to inches Hg:

$$Pg = [Pg \text{ "wg}] * (62.4/846.9) \text{ "Hg}$$

$$= 2.871 * (62.4/846.9) \text{ "Hg}$$

$$= \underline{-0.212} \text{ "Hg}$$

e) Calculate the exhaust stack absolute pressure:

$$Ps = Pbar + Pg$$

$$= 23.177 + -0.212 = \underline{22.965} \text{ "Hg}$$

Step 3: Calculate the molecular weight of the stack gas, Ms

a) From Method 4 or 5: Bws = 0 (Use 0 for dry air)

b) From Method 3: Md = 29 (Use 29 for dry air)

c) Calculate Ms:

$$Ms = (Md * (1 - Bws)) + (18.0 * Bws)$$

$$= (29 * (1 - 0)) + (18.0 * 0)$$

$$= \underline{29} \text{ lb/lb mole}$$

Flow Measurement Calculation Form (Form 6)

Page 2 of 2

This form is from EAQ-127

Step 4: Calculate K

$$a) \quad K = (85.49) * (60) * \sqrt{\frac{T_{s(avg)}}{P_s * M_s}}$$

$$= (85.49) * (60) * \text{SQRT}(522.0 / (22.965 * 29)) = \underline{4541}$$

Step 5: From the field input form, calculate the average velocity head of the stack gas

$$a) \quad (\sqrt{\Delta p})_{avg} = \frac{\sum_{i=1}^n \sqrt{\Delta p}}{n} = \underline{0.659} \text{ inches water}$$

Step 6: Calculate the average stack gas velocity (actual), vs

$$a) \quad v_s = C_p * K * (\sqrt{\Delta p})_{avg} \text{ ft/min}$$

$$= 0.99 * 4541 * 0.659$$

$$= \underline{2964.337} \text{ ft/min} \quad \text{multiply by T and P below; result = 2301.4 std ft/min}$$

Step 7: Calculate the exhaust stack flow rate (actual), Q

a) Record the stack/duct cross-sectional area from profile measurements

$$A = 0.545 \text{ sq ft}$$

b) Q = vs * A

$$= 2964.337 * 0.545$$

$$= \underline{1617} \text{ acfm}$$

Single Point correction ratio:

Overall velocity reading
(above) divided by Avg Sierra
620s reading (earlier):

$$2301 / 2549 = \underline{90.3\%}$$

D. Fuehne, 12/23/2019

Step 8: Calculate the exhaust stack gas dry volumetric flow rate (standard), Qsd

$$a) \quad Q_{sd} = (1 - B_{ws}) * v_s * A * \frac{T_{std}}{T_{s(avg)}} * \frac{P_s}{P_{std}}$$

$$= (1 - 0) * 2964.337 * 0.545 * \frac{528}{522.0} * \frac{22.965}{29.92}$$

$$= \underline{1255} \text{ scfm}$$

T
temp
correction
= 1.011

P
pressure
correction
= 0.768

Section 4.2.4**Stack flow measurement report
Flow Profile 01 (3/4 HP blower)****Flow Configuration 48;
Rigid duct + 48 ft flex duct**

Ecology and Air Quality

Velocity Measurement Input Form (Form 5-M)

Page 1 of 2

This form is from EAQ-127

TA / Building / ES: 35-0034-FTMeasurement Date: 12/03/2019FE(s): 01 Profile Measurement Number: 01 Fan Exhaust Configuration: 48☐ Quarterly/semi-annual airflow measurement ☒ Special measurement ☐ Other _____☐ Method 2 (stack or duct diameter ≥ 12 ") ☒ Method 2C (stack or duct diameter ≥ 4 " but < 12 ")**1. Equipment used and verification**Manometer: EDM Serial #: T58251123035 Calibration Expiration: 04/10/2020Thermometer: EDT Serial #: 140738398 Calibration Expiration: 04/15/2020Humidity Meter: THT Serial #: 140738398 Calibration Expiration: 04/15/2020Pitot Tube: Standard Pitot Tube Serial #: STD-18-01☒ Traverse spacing pre-marked on pitot tube / pitot tube inspected**2. Location inspection**

Location comments: One large U-turn in the flex duct

3. Equipment setup☒ Zero the manometer ΔP Offset 0.000☒ Connect manometer to tubing ☒ Adjust manometer sensitivityPre-test leak check performed (not mandatory) ☐ Yes ☒ No**4. Perform traverse readings** (record velocity pressure in table on appropriate form)Run Start Time: 2:27 PM Run Complete Time: 2:55 PM Average Temperature (Deg F): 62.0**5. Diameter and cross-sectional area of stack or duct (from previous measurements)**Average Diameter (in): 10.000 Area (sq ft): 0.545**6. Post measurement leak test (3" wg)**☒ Successful ☐ Measurement voided**7. Static Pressure and Relative Humidity**SP = -1.239 inches water RH = 29% *(RH recorded for historical purposes only. Not used in calculations. 0% used in calculations)***8. Back purge standard pitot tube and verify** ☐ Not RequiredProfile Location: B 06 Original Reading: 0.298 Verify Reading: 0.298 Percent Difference: 0.17%

Velocity Measurement Input Form (Form 5-M)

Page 2 of 2

This form is from EAQ-127

9. Stack gas dry molecular weight

29.0 (Room Air)

10. Condition which might affect measurements

11. Holes covered

☒ complete

12. Atmospheric pressure

22.96 "HgBarometer location: TA-6 Weather StationElevation: 7424

13. Post measurement Verifications

Test Number	Velocity Pressure (inches wg)		
	Manometer	Reference	% Difference
1	0.161	0.160	0.63%
2	0.441	0.440	0.23%
3	0.851	0.850	0.12%

☒ Manometer Verification Passed (within 5%)

Temperature Reading, °F		Absolute Temperature, °R °R = °F + 460		
Thermometer	Reference	Thermometer	Reference	% Difference
67.4	68.0	527.4	528.0	0.12%

☒ Thermometer verification passed (within 1.5%)

General Comments:

Flow meter velocity reading (ft/min): 1636 - 1670, ~1650

**Average of low & high readings is 1653 standard feet per minute.
This average value used in later calculations.**

Flow measurements were made in accordance with the latest revision of EAQ-127.

Measurements by:

Signature	Lattin, Rebecca	219035	Date
	Print name	Z-Number	

EAQ QA check by:

EAQ review and approval by:

Initials

Original hard copies signed in Rad-NESHAP records.

Stack Gas Velocities (actual) for Individual Velocity Pressure Measurements

TA/Building/ES: 350034FT Fan Exhaust Configuration: 48

Measurement Date: 12/03/2019 FE(s): 01

Profile Measurement Number: 01

Traverse #	Point #	Point Spacing	Velocity Pressure	SQRT(VP)	* Cp	* K	=	Velocity (ft/min)
A	01	1/2	0.263	0.513	0.99	4530		2300
A	02	1	0.281	0.530	0.99	4530		2378
A	03	2	0.292	0.540	0.99	4530		2422
A	04	3-1/4	0.297	0.545	0.99	4530		2442
A	05	6-3/4	0.313	0.559	0.99	4530		2507
A	06	8	0.298	0.545	0.99	4530		2446
A	07	9	0.276	0.525	0.99	4530		2356
A	08	9-1/2	0.256	0.506	0.99	4530		2269
B	01	1/2	0.238	0.488	0.99	4530		2188
B	02	1	0.265	0.515	0.99	4530		2309
B	03	2	0.286	0.534	0.99	4530		2396
B	04	3-1/4	0.294	0.542	0.99	4530		2432
B	05	6-3/4	0.317	0.563	0.99	4530		2525
B	06	8	0.298	0.545	0.99	4530		2446
B	07	9	0.273	0.522	0.99	4530		2343
B	08	9-1/2	0.240	0.489	0.99	4530		2195

Stack Gas Velocities (actual) for Individual Velocity Pressure Measurements

TA/Building/ES: 350034FT Fan Exhaust Configuration: 48
Measurement Date: 12/03/2019 FE(s): 01
Profile Measurement Number: 01

Average stack gas velocity (actual), vs: 2372 ft/min
Exhaust stack flow rate (actual), Q: 1294 acfm
Velocity coefficient of variation (COV): 2.65%
(for center 2/3 of stack area)
Stack type: 2 * 8 Round Stack or Duct
Traverse points eliminated in 2/3 area COV calculation: 01, 08

Data Entered by:

Signature

Data QAed by:

Signature

Measurement Approved

Signature

Print name

Z-Number

Date

Original hard copies signed in Rad-NESHAP records.

Printed on 12/23/2019 6:57:01 PM

Flow Measurement Calculation Form (Form 6)

Page 1 of 2

This form is from EAQ-127

TA/Building/ES:	350034FT	Fan Exhaust Configuration:	48
Measurement Date:	12/03/2019	FE(s):	01
Profile Measurement Number:	01		

Step 1: Calculate the Stack gas average absolute temperature, Ts(avg)

- a) From field input form, determine ts(avg) = 62.0 °F
- b) Calculate the absolute temperature, Ts(avg) = ts(avg) + 460 = 522.0 °R

Step 2: Calculate the exhaust stack absolute pressure, Ps

- a) From field input form, record the barometric reference pressure, Pref = 22.96 "Hg
- b) Adjusting for elevation,
- $$Pbar = Pref + (Elevation[profile] - Elevation[ref]) * (-0.1 \text{ "Hg/100 ft})$$
- $$= 22.96 + (7217.0 - 7424) * (-0.1 \text{ "Hg/100 ft})$$
- $$= \underline{23.167} \text{ "Hg}$$
- c) From field input form, record the static stack pressure, Pg = -1.239 "wg
- d) Convert the static stack pressure from inches w.g. to inches Hg:
- $$Pg = [Pg \text{ "wg}] * (62.4/846.9) \text{ "Hg}$$
- $$= 1.239 * (62.4/846.9) \text{ "Hg}$$
- $$= \underline{-0.091} \text{ "Hg}$$
- e) Calculate the exhaust stack absolute pressure:
- $$Ps = Pbar + Pg$$
- $$= 23.167 + -0.091 = \underline{23.076} \text{ "Hg}$$

Step 3: Calculate the molecular weight of the stack gas, Ms

- a) From Method 4 or 5: Bws = 0 (Use 0 for dry air)
- b) From Method 3: Md = 29 (Use 29 for dry air)
- c) Calculate Ms:
- $$Ms = (Md * (1 - Bws)) + (18.0 * Bws)$$
- $$= (29 * (1 - 0)) + (18.0 * 0)$$
- $$= \underline{29} \text{ lb/lb mole}$$

Flow Measurement Calculation Form (Form 6)

Page 2 of 2

This form is from EAQ-127

Step 4: Calculate K

$$a) \quad K = (85.49) * (60) * \sqrt{\frac{T_{s(avg)}}{P_s * M_s}}$$

$$= (85.49) * (60) * \text{SQRT}(522.0 / (23.076 * 29)) = \quad \underline{\underline{4530}}$$

Step 5: From the field input form, calculate the average velocity head of the stack gas

$$a) \quad (\sqrt{\Delta p})_{avg} = \frac{\sum_{i=1}^n \sqrt{\Delta p}}{n} = \quad \underline{\underline{0.529}} \text{ inches water}$$

Step 6: Calculate the average stack gas velocity (actual), vs

$$a) \quad v_s = C_p * K * (\sqrt{\Delta p})_{avg} \text{ ft/min}$$

$$= 0.99 * 4530 * 0.529$$

$$= \underline{\underline{2372.221}} \text{ ft/min} \quad \text{multiply by T and P below; result = 1850.6 std ft/min}$$

Step 7: Calculate the exhaust stack flow rate (actual), Q

a) Record the stack/duct cross-sectional area from profile measurements

$$A = 0.545 \text{ sq ft}$$

b) Q = vs * A

$$= 2372.221 * 0.545$$

$$= \underline{\underline{1294}} \text{ acfm}$$

Single Point correction ratio:

Overall velocity reading
(above) divided by Avg Sierra
620s reading (earlier):

$$1851 / 1653 = \mathbf{112\%}$$

D. Fuehne, 12/23/2019

Step 8: Calculate the exhaust stack gas dry volumetric flow rate (standard), Qsd

$$a) \quad Q_{sd} = (1 - B_{ws}) * v_s * A * \frac{T_{std}}{T_{s(avg)}} * \frac{P_s}{P_{std}}$$

$$= (1 - 0) * 2372.221 * 0.545 * \frac{528}{522.0} * \frac{23.076}{29.92}$$

$$= \underline{\underline{1009}} \text{ scfm}$$

T
temp
correction
= 1.011P
pressure
correction
= 0.771

4.3 Documentation of FTWC Flow Rate

Date: _____

Location: _____

☐ 2HP system☐ ¾ HP system

1. Duct Setup per IWD? ☐ Yes
☐ No

Tested Duct Configuration:

1. Stack
2. Blower
3. Short 12" section
4. Long 5' section w/ rad monitoring
5. Long 5' section w/ Sierra 620s
6. Short 12" section w/ FTWC inject
7. Flex duct as needed

2. Bounding Condition: minimum velocity achieved on Sierra 620s?

2 HP System:

2680 sfpm on Sierra 620s = 1476 acfm in duct ☐ Yes ☐ No ☐ N/A

¾ HP System:

1404 sfpm on Sierra 620s = 753 acfm in duct ☐ Yes ☐ No ☐ N/A

3. Actual conditions calculations performed? ☐ Yes ☐ No ☐ N/A

 $T_{act} = \underline{\hspace{1cm}}^{\circ}\text{F} = \underline{\hspace{1cm}}^{\circ}\text{R} \quad T_{std} = 70^{\circ}\text{F} = 529.67^{\circ}\text{R} \quad T_{act}/T_{std} = \underline{\hspace{1cm}}$
 $P_{act} = \underline{\hspace{1cm}} \text{ mbar} \quad P_{std} = 1013.25 \text{ mbar} \quad P_{std}/P_{act} = \underline{\hspace{1cm}}$
Pressure correction: -3.4 mbar for every 100 ft difference above reference barometer;

TA-6 weather station = 7424 ft; TA-54 weather station = 6548 ft.

TA-54-1028 is ~6735 ft; -6.4 mbar from TA-54; +23.4 mbar from TA-6

WETF dock is ~7608 ft; -6.3 mbar from TA-6

Use equation 18 to determine flow rate through the duct, based on Sierra 620s reading:

$$\dot{V}_{act} = \left(v_{inst} - 75 \text{ std } \frac{ft}{min} \right) * 0.5454 \text{ ft}^2 * \left(\frac{T_{act}}{529.67^{\circ}\text{R}} \right) * \left(\frac{1013.25 \text{ mbar}}{P_{act}} \right) * 90\% = \underline{\hspace{1cm}} \text{ acfm } (18)$$

4.4 Revision History

4.4 Revision History

This document was originally issued on December 24, 2019. Since that time, several minor changes were made to the document. These are listed below. Change markers in the left border of the main body text show where changes were made. Most significantly, this Section 4.4 (Revision History) and Section 4.5 (Documentation of Peer Review) were added to the document. Other changes to the document for Revision 1 include:

- a) The Abstract was updated to indicate the document had been revised.
- b) Clarification wording was added to the final paragraph in Section 1.2.
- c) In the explanation for Equation 5, the term “volumetric” was added.
- d) The final paragraph of Section 1.3 was added to clarify that the gas calculations are based on ambient air.
- e) In Section 2.4, some sentences were reorganized for clarification; shown in green text.
- f) Also in Section 2.4, the statement about factory calibration of the Sierra 620s was added.
- g) In Table 1, two columns were added to show the range and variability of the Sierra 620s for each flow profile & configuration. This addition was explained in body text after Table 1. A typographical error was also fixed in the Table 1 header.
- h) A sentence describing the “average” Sierra 620s reading follows Table 1.
- i) The final paragraph before Equation 11 explains the “ratio” of duct velocity measured with EPA methods with that value measured with the Sierra 620s.
- j) In section 2.6, a reference was added for the bounding pressure value.
- k) A typographical error was fixed in Equation 16; this equation calculates the bounding velocity reading when using the ¾ HP blower. The equation had incorrectly stated it was for the 2 HP blower.
- l) In the header for Figure 1, the bounding pressure was more accurately stated to be 0.8043 atmospheres instead of 0.805 atmospheres.
- m) In Equation 17, the variables were correctly identified as T_{act} and P_{act} ; they had said T_{bound} and T_{bound} .
- n) The final paragraph in Section 3.4 discusses verifications of the calculations in the Stacks and other RAEM team databases.
- o) In Section 3.5, the reference to the flow documentation worksheet location was updated to indicate Section 4.3.
- p) In the table in Section 4.1, the number of significant digits were made uniform.
- q) The notes on the last page of 4.2.4 were fixed; “122%” was corrected to “112%.”
- r) In Section 4.3, part 3, the Temperature correction term was corrected to T_{act}/T_{std} . The reciprocal of this term was originally stated.
- s) In Section 4.3, part 3, the Pressure correction term was corrected to P_{std}/P_{act} . The reciprocal of this term was originally stated.
- t) In Section 4.3, part 3, the equation for actual volumetric flow was originally listed as Equation 17. This was fixed to reference Equation 18.
- u) The addition of Section 4.4 and 4.5 in their entirety.
- v) Various spelling/grammar corrections were made throughout as needed.

4.5 Documentation of Peer Review

4.5 Documentation of Peer Review

This document was developed over the course of several weeks in late 2019. David Fuehne (EPC-CP, RAEM team leader) wrote the document. Calculations were checked by Rebecca Lattin (EPC-CP). After the document's original publication, it underwent a complete peer review and validation by Mark Bibeault (WFO-WETF), lead engineer for FTWC project.

Specific items that were reviewed are summarized in Table 2. Reviews of the indicated sections are by Ms. Lattin ("RRL") or Mr. Bibeault ("MLB").

Table 2. Peer Review Documentation		
Item	Reference	Reviewers Initials
Section 1.1 Limiting hydrogen concentration.	Hydrogen LEL; OSHA guidance	MLB RRL
Section 1.2 Minimum flow in FTWC system established.	Calculation WETF-CALC-TCV-19-006	MLB RRL
Section 1.3 General theory; Ideal gas law; conversions for ambient temperature and pressure.	Equations 1-6	MLB RRL
Section 2.0 Defining standard conditions for process.	Sierra 620s manual	MLB RRL
Section 2.1 Correction for meter uncertainty.	Equation 7	MLB RRL
Section 2.2 Converting linear velocity to volumetric flow rate	Equations 8-9	MLB RRL
Section 2.3 Correction from standard conditions to ambient conditions.	Equation 10	MLB RRL
Section 2.4 Review of Table 1 data and flow ratios	Flow reports attached in Sec. 4.2.	MLB RRL
Section 2.4 Correction for single-point flow measurement	Equation 11	MLB RRL
Section 2.5 Final flow correction equation	Equation 12	MLB RRL
Section 2.6 Bounding condition equation	Equation 13	MLB RRL
Section 2.6 Determination of bounding conditions; 805 mb, 32°F	LANL weather data; project files	MLB RRL
Section 2.6 General equation for bounding velocity reading on Sierra 620s	Equation 14	MLB RRL
Section 2.6 Calculation of minimum flow rate on Sierra 620s for large 2HP blower	Equation 15	MLB RRL
Section 2.6 Calculation of minimum flow rate on Sierra 620s for smaller 3/4 HP blower	Equation 16	MLB RRL

4.5 Documentation of Peer Review

Table 2. Peer Review Documentation		
Item	Reference	Reviewers Initials
Section 2.7 Determination of sufficient flow for various "actual" temperatures & pressures	Equations 17 & 18	mJB RRL
Section 2.7 Determination of minimum Sierra 620s reading at various "actual" temperatures and pressures	Equations 19 & 20	mJB RRL
Section 2.7 Determination of minimum Sierra 620s reading, specific for two blowers	Equations 21 & 22	mJB RRL
Section 3 Field implementation process	Overall process in Section 3.1 - 3.5	mJB RRL
Section 4.1 Ambient air pressure vs. elevation table	Elevation correction factor development.	mJB RRL
Section 4.2 Flow test data packages	Complete packages; hand-calculated ratios; data correctly entered into Table 1.	mJB RRL
Section 4.3 Documentation of FTWC flow rate field worksheet	Correct equation references; process matches Section 3.	mJB RRL

Developed and reviewed by:

115862

Z#

David Faehne, author

Printed Name



Signature

1/28/2020

Date

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Signature

1/29/2020

Date